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ADVANCED AQUARIST'S ONLINE MAGAZINE

The Best Lamp Is...
The Carbonate System in the Aquarium
Conductivity and Salinity
Information Resources for Home Aquarists

photograph by Peter Siegel

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Acanthurus leucosternon, Powder Blue Tang/Surgeonfish (main); Peter Wilkens -- In memoriam (inset). Photos by Terry Siegel.

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EDITORIAL

DECEMBER 2008

By Terry Siegel

Create a thriving reef tank or spend some time in scuba gear observing a tropical reef and you are likely to care about and fight for what remains of the wild coral reefs of the world.

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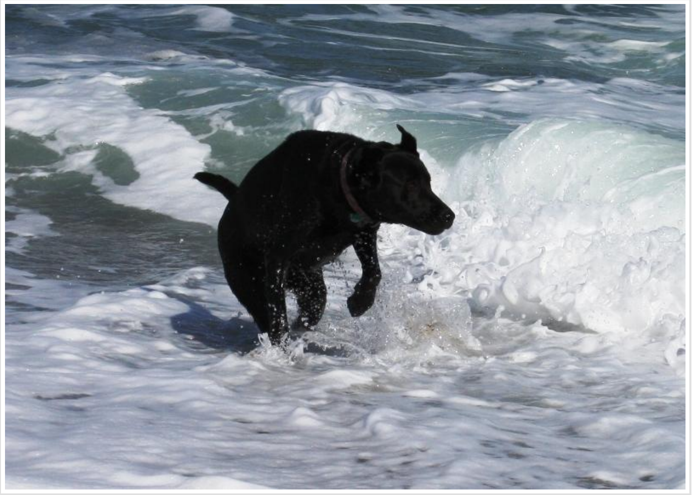
When non reef keeping folks come over to view my reef tank along with the "how beautiful" and "what's that strange thing with the bubbles" some of the more thoughtful sometimes ask if it's fair to these beautiful reef fish to have to spend their lives imprisoned between walls of glass or plexiglas. "Your tank is beautiful, but it's not the ocean."

This is certainly a fair question, but I think without being too self-serving that there are legitimate answers. For one thing, reef fish on average in a successful reef tank live much longer that those on the natural reef – predation by larger fish, especially reef sharks, take a huge number in the wild. For another, competition for food and space is usually less severe in captivity.

Far more important than these answers relates to the question of our time: survival of life on our planet. It is the folks that struggle to successfully establish a reef tank, or to teach fledgling Whopping Cranes to fly, or to save Polar Bears from starving due to global warming, who because of their intimate contact with these and other animals are among those that care. If you don't love the animals that inhabit your reef tank, and understand the biochemical elements that are necessary to maintain a successful reef tank then it is unlikely that you will be a successful reef keeper. For example, reef keepers know what it means to a maintain a good carbonate balance, and therefore understand what scientists worry about when talking about the acidification of the world's oceans. From ones reef tank it is an easy step to recognizing the beauty and complexity and fragility of a natural reef. And more importantly, to want to fight for the survival of Nature, in all of its manifestations.

Though I doubt if such a poll was ever taken, I'm willing to bet that if you polled reef keepers, dog and cat owners, etc. compared to folks that haven't made animals part of their lives you would find a much higher desire to fight for the survival of Earth's animal diversity amongst these biophiles. Biophiles are folks who have an affection for nature, as opposed to necrophiles, who prefer dead things like toasters or televisions, etc. One is much more likely to fight for Nature's survival if you have intimate contact with Nature. Create a thriving reef tank or spend some time in scuba gear observing a tropical reef and you are likely to care about and fight for what remains of the wild coral reefs of the world.



My dog Smudge, a black female Lab rescue, having fun in the surf at Cape Cod.

FEATURE ARTICLE

THE BEST LAMP IS...

By Dana Riddle

Recent research has suggested a 'best lamp' - but some caveats exist!

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Debates about 'the best light' for illuminating reef aquaria have raged among hobbyists for years. There has been little doubt that corals, as a group, can adapt to varying degrees of light intensity and spectral quality. The proof has been obvious to veteran hobbyists, especially those who remember the early days of the hobby when a metal halide with the 'warm' Kelvin rating of 5,500 was considered to be on the cutting edge of technology and could maintain a number of coral taxa alive within captive environments. Since those days, of course, there have been many innovations introduced into the aquarium lighting arena and these have only added to the number of arguments. Fortunately, researchers have recently generated statistically significant data concerning the effects of different spectral qualities on coral growth and longevity. This article will review this information, and will offer further data in support of a pet theory of mine - the 'red light theory.'

Recent research has suggested a 'best lamp' - but some caveats exist! Only metal halides were used, and apparently the sample size was small (2 lamps each of 4 various Kelvin ratings). No other types of lamps were tested (i.e., fluorescents, LEDs, etc.). One coral species - an *Acropora* species collected from approximately the same depth on the same reef - was used in the experiment. In addition, the coral fragments were attached to two different substrates (marble and cement). With this in mind, we can examine these experiments and their results.

THE EXPERIMENTS

Schlacher et al. (2007) conducted experiments one of each of these 150-watt lamps: 5,500K, 10,000K, 14,000K and 20,000K (Table 1 lists the brands or manufacturers). Five colonies of a single coral species (a 'tabletop' coral, *Acropora solitaryensis* - Figure 1) were randomly collected at a depth of 14m (~46 feet) on Australia's Great Barrier Reef. These colonies were broken into ~300 fragments, which were distributed among eight 105 liter (~29 gallon, 26"L x 16"W x 16"D) aquaria. Powerheads provided circulation.

RESULTS

These researchers presented their results in two main categories: Growth rates and survival rates. I've chosen to examine results of growth rates, and for these reasons.

Anyone familiar with 'fragging' corals knows that, even under the very best of circumstances, survival of corals after fragmentation sometimes seems to be due to the fickle hand of fate. The amount and quality of light and water motion will surely play a part in determining the ultimate fate of broken corals as they adapt to a new environment, as will be amount of trauma suffered during the fragmentation process. With this said, I'll assume that we cannot assign losses to lighting issues alone, and have chosen to look at the long term effects of lighting and how it affects coral growth rates. It should be noted that these researchers felt the type of substrate played a marginal role in determining survival rates. With this said,

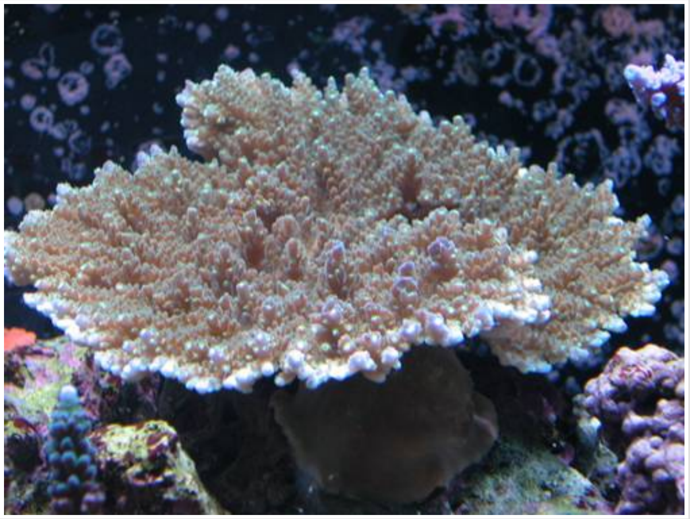

Figure 1. An Acropora solitaryensis demonstrating the 'tabletop' growth form. Photo courtesy of Steve Ruddy and Coral Reef Ecosystems.

Table 1: Lamps Used in Schlacher et al's Experiment

Kelvin *	Brand	Manufacturer
5,500	Osram	Osram
10,000	BLV	Ushio
14,000	Hikari Arcadia	?
20,000	HIT Colorlite	Ushio
* Kelvin is that advertised by the manufacturer.		

Figure 2 shows the growth rates of *Acropora solitaryensis* during the third month of the Schlacher et al. experiments.

DISCUSSION

Schlacher et al. (2007) presented their results but made no comments concerning possible reasons for observed differences in coral growth under different light regimens. There are several ways to examine the data, beginning with:

OVERALL INTENSITY OF PUR GENERATED BY THE LAMPS

Photosynthetically Usable Radiation (PUR), for our purposes, is that portion of Photosynthetically Active Radiation (PAR; those wavelengths of the violet to red portions of the visible spectrum) that is absorbed by one or more photopigments found in corals' symbiont algae (zooxanthellae). Specifically, Schlacher and crew determined PUR through spectrometer measurements of each lamp's spectral qualities (using the absorption bandwidths of chlorophyll *a*, specifically wavelengths of 400-450nm and 650-700nm). If PUR is the determining factor, we would expect to see growth rates producing increased growth (if there is no dynamic or chronic photoinhibition occurring) or decreased growth trending with the amount of PUR if photoinhibition is happening. We do not see a correlation either way, and I tend to discount PUR as the determining factor in these particular cases. See Figure 3.

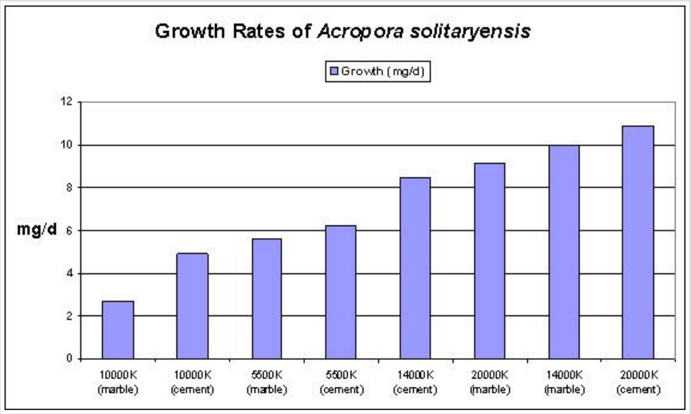

Figure 2. Growth rates of Acropora solitaryensis during the third month of the experiment, listed by lamp and substrate combinations.

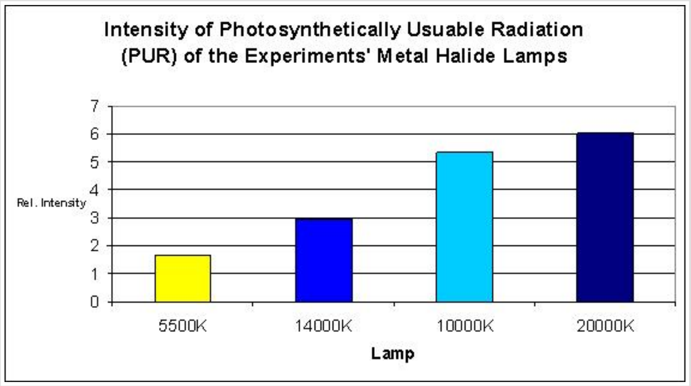

Figure 3. Amounts of PUR generated by metal halide lamps of various Kelvin ratings.

BLUE LIGHT GENERATED BY THE LAMPS

If blue light were the deciding factor in promoting growth within the coral samples used in the experiments, we could expect a trend to fall along the blue light intensity of the various lamps. When we compare the amount of blue light (Figure 4) to the growth rates (demonstrated in Figure 2), we see no trend.

RED LIGHT GENERATED BY THE LAMPS

While no trend seems apparent with either PUR intensity or the amount of blue light generated by these lamps and *Acropora solitaryensis* growth rates, the same can not be said when we examine the amount of red light and how it correlates with coral growth. See Figure 5. The more red light a lamp generates correlates fairly well with low growth rates.

THE RED LIGHT THEORY REVISITED

In order for a hypothesis to advance to a theory, there must be some sort of evidence from experiments in support of the idea. The following presents the evidence in support of the 'red light theory.'

Hawaiian researchers, in the 1980's, found that exposure to broad bandwidth red light resulted in low growth rates in corals (Kinzie et al., 1984). Further experiments (Kinzie and Hunter, 1987) found that

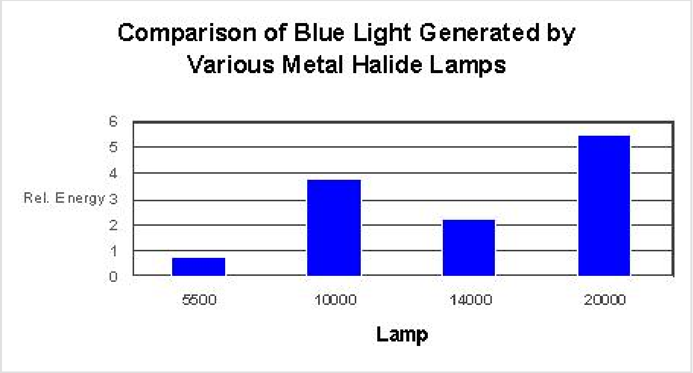

Figure 4. Blue light generated by various Kelvin lamps used in Schlacher's experiments.

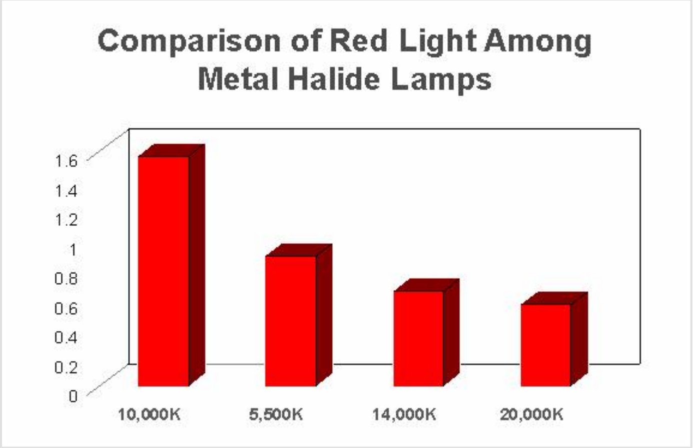

Figure 5. The amount of 'red light' (650-700 nm) generated by four metal halide lamps.

corals exposed for more than 60 days to light composed of mostly the red portion of the spectrum resulted in corals that "...were almost entirely free of algae and appeared white, but retained complete coverage of living animal tissue. We have not been able to obtain this degree of bleaching with any other method, including prolonged shading."

Results from further experiments would suggest that red light generated by light-emitting diodes (LEDs) can induce coral bleaching. Experiments conducted in early 2002 (see http://advancedaquarist.com/issues/june2004/feature.htm) demonstrated that narrow bandwidth red light produced by an LED in underwater housings caused bleaching in the stony coral *Pocillopora meandrina*. I conducted later experiments in 2004 that resulted in bleaching of an expanded selection of corals (including stony corals *Porites*, *Pavona*, *Pocillopora* and unidentified zoanthids - see Figures 6 and 7).

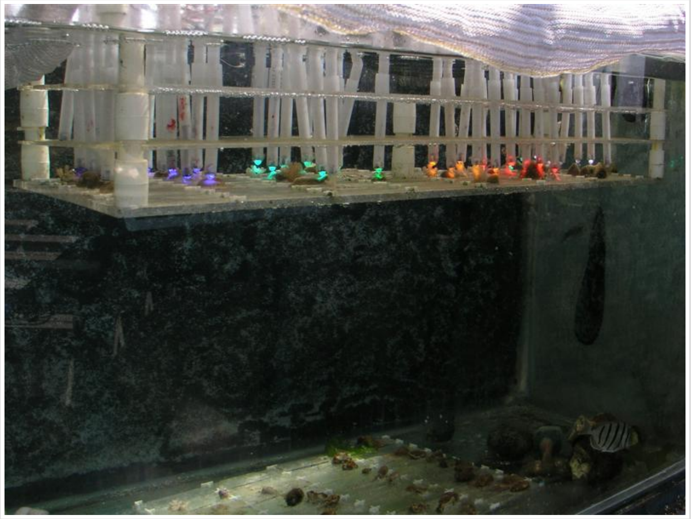

Figure 6. The LED/coral experiment to determine effects of various narrow bandwidth light on corals.

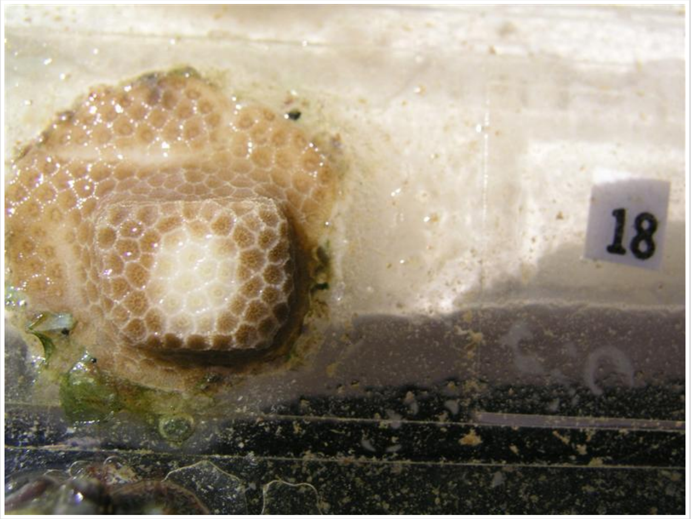

Figure 7. Effects on a Porites coral of light skewed towards the red portion of the spectrum as determined under the circumstances shown in Figure 6. Red light intensity was low at 160 µmol·m^{2}·sec.

In light of the evidence, should we really be surprised that red light can possibly be detrimental to at least some corals' zooxanthellae? Just a quick look at Figure 8 confirms that many corals are found in environments deficient in red light. 'Strong' red light is unnatural and seems to be a factor in regulating zooxanthellae density and/or pigment content.

The work of Schlacher, Stark and Fischer is important, and a great stride in improving our understanding of the effects of artificial light on coral growth and survival.

However, we should remember that these results are from experiments with a single species collected from a specific depth and geographical location. This information may, or may not, be applicable to other corals. Clearly, more research is needed, but this does not lessen the importance of these researchers' results.

In addition, we should also note that Kelvin ratings are a poor indicator of true spectral quality - that is, it is a mistake to judge the 'warmness' or 'coolness' of a lamp when Kelvin is based on measurements made of lamps possessing 'spiky' line spectra such as mercury vapor or metal halides.

Question or comments? Contact me at RiddleLabs@aol.com.

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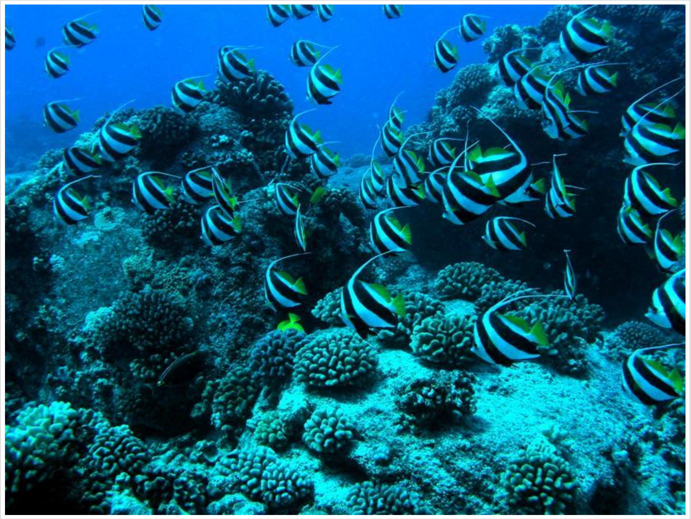

Figure 8. The blue waters of Kailua-Kona, Hawaii, at a depth of ~13 meters.

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AQUARIUM CHEMISTRY

THE CARBONATE SYSTEM IN THE AQUARIUM, AND THE OCEAN, PART I: THE COMPONENTS OF THE CARBONATE SYSTEM

By Chris Jury

By understanding the carbonate system and using that knowledge to our advantage it is possible to encourage rapid calcification and growth in many of the calcifying organisms we maintain in captivity.

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Let's start with a simple observation: many of the organisms that live in the ocean and that we keep in our aquariums produce hard shells or skeletons. Corals build intricate structures beneath their tissues; clams, snails, shrimp, and many others produce hard parts; coralline algae, *Halimeda* spp. and some other algae reinforce their tissues too. Producing these structures is fundamental to the way in which these organisms live. The shells/skeletons provide the organisms that make them protection from predators and from harsh environmental conditions, and support their tissues, just as our bones support our bodies. All of these organisms calcify. That begs the question of what we mean when we say that they calcify; in other words, what is calcification? For a simple definition of calcification we might say it is:

Calcification: The process of precipitating calcium-rich minerals over an organic matrix.

If we use the analogy of constructing a building, the organic matrix, which is composed of specialized organic molecules made by the calcifying organisms, is rather like the scaffolding of the building. It is a small portion of the skeleton/shell and doesn't provide any real strength, but instead provides the general pattern that allows the structure to begin taking shape. Calcium-rich minerals (various types of $CaCO_3$ in these organisms) are like the concrete and the mortar that gives a building strength and provides the bulk of the structure.

An important point to consider is that these organisms are calcifying purposefully. Calcification is not simply a consequence of their activities, but rather a process they are putting energy and resources into. Calcium carbonate and other carbonates can and do precipitate abiotically both in our aquariums and in nature, without the aid of calcifying organisms, but at a fairly slow rate. It takes a great deal of energy and investment by these organisms to calcify at the high rates that are typical for them. Calcification is a process under strong biological control, though it is also strongly influenced by environmental conditions.

The rate that some organisms calcify may relate to how fast they can grow. For instance, corals that calcify faster are usually the ones that are able to grow faster, though the relationship between growth and calcification is not entirely straightforward. The rate of calcification and growth in corals can vary substantially for any given species, depending on environmental conditions. For example, rates of linear extension for the Caribbean Staghorn coral (*Acropora cervicornis*) have been measured in nature as low as 1 in yr^{-1} (Crabbe and Carlin, 2007) and as high as 10 in yr^{-1} (Lewis et al., 1968). If those growth rates were realized in an aquarium it would mean the difference between a golfball-sized coral colony growing into a baseball-sized colony in a year, or into a larger than basketball-sized colony in the course of that same year. That is a very big difference indeed. Most aquarists would probably prefer higher growth rates from their corals and other organisms where possible. Faster growing organisms means that we have larger, more attractive animals in shorter periods of time, and more coral frags to trade and sell. It means a greater reward for our efforts and reduced impact on wild reefs by lessening the demand for wild-collected animals, both of which are very positive outcomes.

So how do we encourage our corals, clams, and other critters to grow quickly in our aquariums? What sorts of environmental conditions will favor growth rates near the upper end of the normal range, instead of nearer the lower end? Unfortunately there is no simple or single response sufficient to answer these questions, but there is a lot we can do to help our charges attain higher (and healthy) growth rates in captivity.

One of the most important considerations in encouraging rapid, healthy growth in corals and other calcifying organisms, and one that aquarists often struggle with, is in providing appropriate carbonate chemistry in our aquariums. Doing so involves manipulating several interacting variables, namely calcium concentration [Ca^{2+}], magnesium concentration [Mg^{2+}], total alkalinity, total CO_2 and pH. These various parameters work together to form the carbonate system in sea water. Depending on how successful we are at manipulating these parameters we can arrive at conditions that allow for the rapid calcification and growth of our charges, or we can arrive at conditions that cause their calcified structures to dissolve away… literally. Providing appropriate carbonate chemistry in our aquaria is, more than almost any other consideration, absolutely critical to the continued good health and growth of our calcifying organisms.

Table 1. Concentrations of the 11 major components of sea water. Values are reported for standard sea water (S = 35.000). After Millero, 2006.

Component	g kg^{-1}	ppm	mmol kg^{-1}
Cations			
Na^+	10.7838	10,783.8	469.07
Mg^{2+}	1.2837	1283.7	52.82
Ca^{2+}	0.4121	412.1	10.28
K^+	0.3991	399.1	10.21
Sr^{2+}	0.0079	7.9	0.09
Anions			
Cl^-	19.3529	19,352.9	545.88
SO_4^{2-}	2.7124	2,712.4	28.24
$HCO_3^- + CO_3^{2-}$	0.1231	1231	2.02
Br^-	0.0672	67.2	0.84
$B(OH)_3 + B(OH)_4^-$	0.0272	27.2	0.41
F^-	0.0013	1.3	0.07

While it is one of the most important aspects of keeping marine aquaria, few issues generate as many questions, or as much confusion, as how these parameters relate to each other, how best to go about manipulating them, and what sorts of targets to aim for with each of these parameters. In this series I will address all of these issues, and in ways that hopefully will make sense (or at least more sense) of this intriguing, complex system. But, as is always the case, it's very hard to understand the significance of what we're talking about if we don't first understand *what* it is we're talking about. This article will discuss each of the components of the carbonate system in sea water: what they are, what typical values are in natural sea water, and generally why they matter to aquarists.

THE MAJOR COMPONENTS OF SEA WATER

To begin, let's consider what is dissolved in sea water. Sea water is a complex chemical soup of dissolved minerals, dissolved gases, and a variety of dissolved and particulate organic materials. Salinity is a measure of the sum total of the dissolved minerals. To measure salinity, ideally we would like to be able to simply allow the water to evaporate away and measure the mass of the dissolved minerals. Unfortunately, when sea water is dried some of the components (namely carbonates and some halides) are lost to the atmosphere as gases. Several corrections have been used historically to take account of these losses, but the procedure to determine absolute salinity is very impractical for every-day use. Instead salinity is measured using the Practical Salinity Scale based on conductivity, or a related physical property such as refractive index or specific gravity. Because of the historical corrections needed in defining how salinity is measured there are actually slightly more than 35 g of dissolved minerals in 1 kg of sea water at a standard salinity of 35.000 (~35.171 g kg^{-1}). Different dissolved components contribute distinct amounts to that total. For convenience, oceanographers typically split the components of sea water into three categories: major, minor, and trace components

Major components are those that contribute significantly to salinity. Since salinity is typically reported to 0.001 (1 ppm) by oceanographers, the components that typically have a concentration of 1 ppm or higher constitute the 11 major components of sea water. Minor components and trace elements are those that typically have a concentration lower than 1 ppm and therefore do not contribute measurably to salinity. The 11 major components and their typical concentrations in standard sea water are listed in Table 1. The contribution of these species to the total mass of dissolved solids can be seen in Figure 1. These 11 components include many of the components of interest for our discussion of carbonate chemistry.

The major components as well as some minor components of sea water show conservative behavior, meaning that the ratio of their concentration to salinity is constant in the ocean from place to place. Another way to say this is that the concentrations of these components are essentially the same in sea water everywhere around the world at a given salinity. A change in salinity therefore represents simply the gain or loss of water. Whether we measure the sea water in the Caribbean, off of Australia, Zanzibar, Finland, or Argentina, for any given salinity we'll find the same concentration for all components that show conservative behavior. We can compare the concentration of a component from one place to another by normalizing the value to salinity as described by,

$$[M_N] = [M] \times (35/S)$$

The normalized concentration $[M_N]$ is equivalent to the concentration measured in our sample $[M]$ times the ratio of standard salinity (35) to the salinity of our sample (S).

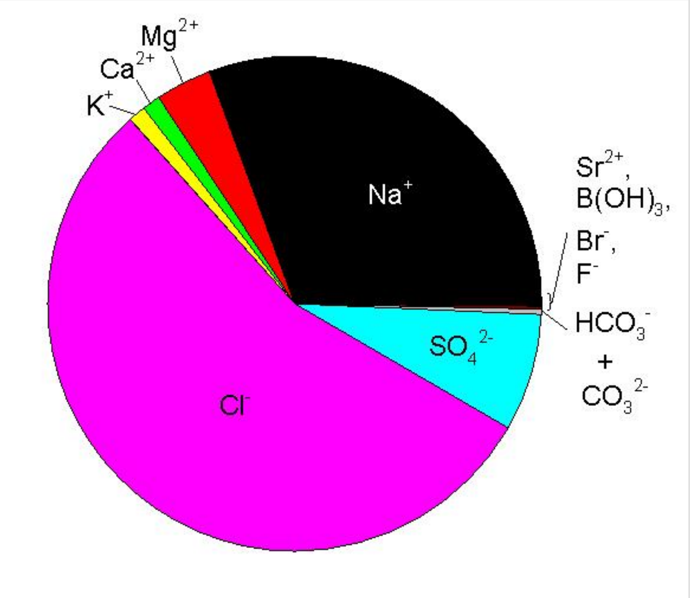

Figure 1. The relative mass contribution of the 11 major components of sea water to the total mass of dissolved solids. Values are for standard sea water.

While the major components of sea water are generally conservative, this behavior can break down in some areas due to local processes. A few examples where conservative components may not be conservative are:

1. Estuaries, where the outflow of rivers tends to disproportionately add Ca^{2+} and alkalinity, raising their ratios to salinity.
2. The deep sea, where the dissolution of $CaCO_3$ tends to elevate both Ca^{2+} and alkalinity relative to salinity. Due to the remineralization (= decomposition) of organic material, which tends to reduce the alkalinity slightly, the increase in alkalinity is smaller than that for Ca^{2+}.
3. Deep sea vents, which tend to reduce Mg^{2+}, SO_4^{2-}, and alkalinity relative to salinity.

Now let's look more closely at the components of the carbonate system.

CALCIUM AND MAGNESIUM

Typically the units of measure used by aquarists to express Ca^{2+} and Mg^{2+} concentrations are ppm (parts per million). Normalized to a salinity of 35, the concentration of Ca^{2+} in sea water is about 412 ppm while that of Mg^{2+} is about 1284 ppm. That means that in 1 kg of sea water at a salinity of 35 we have 0.412 g Ca^{2+} and 1.284 g Mg^{2+}. Of the parameters we will discuss, these two are probably the easiest for aquarists to visualize. When we measure the concentration of Ca^{2+} or Mg^{2+} we are simply measuring the mass of each ion dissolved in 1 kg of sea water.

While it is useful to discuss these parameters with regard to standard seawater (S = 35), salinity is not constant in the ocean. In areas where freshwater input (from rain and runoff) exceeds evaporation, the salinity of surface water drops. In areas where evaporation exceeds freshwater input, salinity rises. Salinity varies not only from region to region, based on local processes, but also seasonally in some places. While reefs may occur where the average salinity ranges from as low as 30 to as high as 42, most coral reefs occur where the average salinity is within the range 33-37. The concentrations of Ca^{2+} and Mg^{2+} will be about the same everywhere in the ocean when normalized to salinity, but variation in salinity from place to place means that there is some variation in Ca^{2+} and Mg^{2+} concentrations as well. For a salinity range of 33-37 we'd expect a range in Ca^{2+} concentration of about 388-436 ppm and a range in Mg^{2+} concentration of about 1211-1357 ppm. Local processes can affect these values slightly as well. For example, coral reefs actively precipitate Ca^{2+} and to a smaller extent Mg^{2+} from the water column to form carbonate minerals, leading to slightly lower values for both. Dissolution of those minerals can also occur in parts of the reef (especially at night) yielding slightly higher values for Ca^{2+} and Mg^{2+} concentrations. Variation in Ca^{2+} and Mg^{2+} concentrations due to precipitation or dissolution of minerals on reefs is relatively small though (typically less than 10 ppm for Ca^{2+} and less than 3 ppm for Mg^{2+}). Areas where upwelling occurs (e.g., Galapagos) may also experience slightly higher concentrations of Ca^{2+} as compared to areas that do not experience upwelling.

These two parameters are important for us to consider because both Ca^{2+} and Mg^{2+} (principally Ca^{2+}) are building blocks used by calcifying organisms to build their skeletons. As we will see, Mg^{2+} plays

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an additional role in affecting the solubility of $CaCO_3$ in sea water and rate of $CaCO_3$ precipitation.

pH

Folks often have a bit more trouble understanding what pH actually measures as compared to a parameter such as Ca^{2+} concentration or Mg^{2+} concentration. This is an unfortunate artifact of the complicated-looking logarithmic scale used to express pH.

pH is how we show the quantity of hydrogen ions (H^+, also referred to as "protons") in water. Most quantities we measure are measured on linear scales. For example, a dumbbell that weighs 10 kg weighs twice as much as one of 5 kg and half as much as one of 20 kg. The logarithmic scale used to measure pH means that we see changes in $[H^+]$ that are orders of magnitude different: pH = 1 is ten times as acidic as pH = 2 and one million times as acidic as pH = 7.

pH is defined according to the following equation:

$$pH = -\log(H^+)$$

where (H^+) is the activity of hydrogen ion. For water with very low ionic strength (very few dissolved ions), activity and concentration are essentially the same thing. We measure (H^+) in molar units, that is, moles per liter of solution. Recall that 1 mole = Avogadro's Number of particles (6.022×10^{23}). If our solution has pH = 1 then we have an H^+ concentration of 1×10^{-1} mol L^{-1}. If the solution has pH = 7 we have an H^+ concentration of 1×10^{-7} mol L^{-1}. We could rewrite the equation above as

$$(H^+) = 1 \times 10^{-pH}$$

Hence, a change of one pH unit means a change of one order of magnitude of (H^+). A handy conversion to keep in minds is that a decrease of 0.3 pH units means we double (H^+); an increase of 0.3 pH units means we cut (H^+) in half. For example, at pH = 8.5, (H^+) is half what it is at pH = 8.2. At pH = 7.9, (H^+) is twice what it is at pH = 8.2. Even a relatively small change in pH means a big change in (H^+), and potentially a big effect on any process influenced by pH.

While it is true that at very low ionic strength ion activity is essentially equivalent to ion concentration, as more and more ions are dissolved in water they begin to interact with each other in ways that makes the solution appear to have fewer ions than are actually present. That is, ion activity is lower than ion concentration in salty solutions. In sea water we have lots and lots of dissolved ions. H^+ interacts strongly with SO_4^{2-} to form HSO_4^- ion pairs, and with F^- to form HF ion pairs. These ion pairs are short-lived, constantly forming and breaking apart, but nonetheless they affect the activity of H^+. pH probes can only detect free H^+ in water, not HSO_4^- or HF, so in effect that means that when we measure the pH of sea water we are only measuring a portion of the H^+ present (~72.66% of the total concentration). This has important implications for chemists and oceanographers and has led to the development of alternative pH scales for use in complex solutions, like sea water (the Total Scale, the Seawater Scale, and the Free Scale).

The pH scale used by aquarists and in most other applications is the one based off of buffers from the National Institute of Standards and Technology (NIST, formerly NBS, the National Bureau of Standards). Since the various pH scales are defined slightly differently, they give slightly different results. For example, standard sea water yields $pH_{NIST} = 8.20$, $pH_T = 8.06$, and $pH_{SWS} = 8.05$ for the NIST, Total, and Seawater scales, respectively. Hence, the pH values quoted for sea water by oceanographers will be slightly lower than those measured by aquarists (by ~0.15 units). Hereafter, whenever I mention pH values they will be reported using the NIST scale used by aquarists. I mention the other pH scales so as to (hopefully) ease confusion for aquarists that may speak with oceanographers or read their writings. The pH of sea water measured by aquarists is ~0.15 units higher than the pH measured by oceanographers simply because we use different scales of measure.

For our purposes the important thing to understand is that a pH measurement is telling us the quantity of H^+ in the water and that the logarithmic scale used to measure pH means that a small change in pH represents a large change in (H^+). Remember, an increase of 0.3 pH units means (H^+) is cut in half; a 0.3 unit decrease means (H^+) is doubled.

The pH in today's shallow ocean averages 8.20, which is lower than the mean of 8.30 during the pre-industrial period. We'll discuss why oceanic pH is lower today than it was in the recent past in later segments. In the open ocean, pH doesn't vary much over the course of a day (perhaps 0.02 units), though it may show some seasonal variation related to variation in primary production. Around coral reefs we see a much higher density of organisms than in the open ocean. Their activities cause the pH in the water overlying reefs to vary much more than in nearby oceanic systems. Even on well-flushed outer reefs it's not unusual to see a range of 0.2 pH units per day (e.g., pH ~8.1-8.3 over a 24 hr period). On reef flats, in lagoons, and areas with restricted water exchange it is possible to see much more variation in the course of a day. On some reef flats pH values have been measured to vary from as low as 7.8 to as high as 8.4 in a single 24 hr period (Yates and Halley, 2006). In some lagoons, pH has been measured to vary as much as 1 pH unit in a day (e.g., 7.6 to 8.6). Seasonal and even multi-decadal cycles of pH variation in reef water have also been measured (Pelejero et al., 2005). While some of the pH values that organisms see in the field may be less than ideal for growth, many are able to tolerate a fairly wide range of pH values, at least for short periods of time.

One last point worth considering is that water (H_2O) dissociates to produce two ions: hydrogen ion, H^+, and hydroxide ion, OH^-. The concentrations (technically the activities) of these two are inversely related. When there are a lot of H^+ (low pH) there are few OH^- and when there are few H^+ (high pH) there are lots of OH^-. Typically we think of pH = 7.00 as a neutral pH, meaning that $(H^+) = (OH^-)$. While this is true at standard conditions (T = 25 °C, P = 1 atm) in a solution of low ionic strength, as temperature or pressure are changed, or in a solution of high ionic strength like sea water, the pH where $(H^+) = (OH^-)$ changes slightly as well.

pH is an important parameter for us to consider for several reasons. Firstly, many physiological processes in living organisms are strongly affected by pH. If the pH of our tank water is substantially high or low, it may have direct, negative impacts on many of the organisms in our tanks, not just the calcifying organisms. In addition, pH plays a very important role in affecting the rate of $CaCO_3$ precipitation and dissolution, as we will see.

TOTAL CO_2

The parameters we've discussed to this point are relatively straightforward. Calcium and magnesium concentration are merely the quantity of Ca^{2+} and Mg^{2+} dissolved in the water. While pH is measured using a somewhat cumbersome scale, it is merely the (apparent) quantity of H^+ dissolved in the water. Discussing dissolved CO_2 in water is necessarily more complex because instead of simply taking into account a single chemical species (Ca^{2+}, Mg^{2+}, or H^+) here we must consider four different chemical species.

In the atmosphere, CO_2 is a gas. That's simple enough. When CO_2 dissolves into water, however, some of it reacts chemically with that water to produce carbonic acid:

$CO_2(aq) + H_2O \leftrightarrow H_2CO_3$

In analytical chemistry, it is usually difficult to distinguish $CO_2(aq)$ from H_2CO_3, so the two are combined in a single term: CO_2^* ($[CO_2^*] = [CO_2(aq)] + [H_2CO_3]$). Some of the carbonic acid will dissociate to produce a proton and a bicarbonate ion:

$CO_2^* \leftrightarrow H^+ + HCO_3^-$

Some of the HCO_3^- will dissociate to produce a proton and a carbonate ion:

$HCO_3^- \leftrightarrow H^+ + CO_3^{2-}$

If we put all of that together we have a chemical equilibrium that looks like this:

$CO_2^* \leftrightarrow H^+ + HCO_3^- \leftrightarrow 2H^+ + CO_3^{2-}$

It looks complicated, but let's consider what it's telling us. There are four different forms that CO_2 takes in water (whether sea water or freshwater), though we've combined two of those terms for convenience. Since these chemical species interact with H^+ we can see right away that the proportion of each will depend on the pH. If we have lots of H^+ (= low pH) then the CO_3^{2-} and HCO_3^- will take up some of the H^+ and we will have mostly CO_2^*. If we have very few H^+ (= high pH) then the CO_2^* and HCO_3^- will lose H^+ and we will have mostly CO_3^{2-}. At intermediate pH we'll have mostly HCO_3^-, some CO_2^*, and some CO_3^{2-}.

For many calculations in oceanography it is useful to know the total amount of CO_2 in the water, regardless of which form it has taken. We call this parameter, aptly enough, total CO_2, or TCO_2. TCO_2 is also written as CO_2 and is equivalent in meaning to DIC (dissolved inorganic carbon). It is defined simply as the sum of the concentrations of each form of CO_2,

$TCO_2 = [CO_2^*] + [HCO_3^-] + [CO_3^{2-}]$

Consulting Figure 2 we can see that in sea water at normal pH (= 8.20) we have mostly HCO_3^- (~88.4%), some CO_3^{2-} (~11.0%) and only a small amount of CO_2^* (~0.54%). Of course, these proportions will change immediately if pH changes. If we add a strong acid (e.g., HCl) or a strong base (e.g., NaOH) to sea water, we will change the pH of that water, thereby changing the speciation of CO_2. The pH therefore affects the speciation. However, we must also consider that if we add any of the CO_2 species to sea water we will also affect the pH. For example, if we bubble $CO_2(g)$ into the water we will form carbonic acid, produce H^+, and thereby lower pH. If we add CO_3^{2-} some of the H^+ in solution will be taken up to produce HCO_3^- and thereby raise pH. Temperature and pressure slightly affect the tendency of CO_2^* to dissociate into H^+ and HCO_3^- as well as the tendency of HCO_3^- to dissociate into H^+ and CO_3^{2-}. Said another way (for any chemists out there), temperature and pressure shift the dissociation constants pK1 and pK2 for carbonic acid. Varied salinity affects the activity of these species and thereby affects the apparent dissociation constants in sea water (pK1` and pK2`).

TCO_2 can be measured directly, but doing so requires relatively sophisticated equipment. Instead of measuring TCO_2, aquarists infer whether the TCO_2 in their aquaria is high, low, or just right by measuring 1) tank pH, and 2) alkalinity, the next parameter of our discussion. For sake of completeness I will simply note that the TCO_2 of standard sea water in equilibrium with today's atmosphere is about 1991 µmol kg^{-1}. TCO_2 in sea water can vary over both short and long timescales, and variation in TCO_2 has important consequences for our aquaria, and the ocean.

TCO_2 is an important parameter for us to consider because the interaction between this parameter and total alkalinity largely controls the pH of sea water. TCO_2 therefore plays a critical role in determining the rate of $CaCO_3$ precipitation. TCO_2 also affects the rate of photosynthesis in many organisms, which can further affect the rate of calcification in calcifying, photosynthetic organisms like corals and tridacnid clams.

TOTAL ALKALINITY

Oceanographers use the term total alkalinity whereas aquarists usually refer to the same property simply as alkalinity. We'll see below why oceanographers include "total" to describe this aspect of seawater chemistry. I've saved alkalinity as the last parameter we'll discuss because it is perhaps the most confusing for most aquarists. Indeed, even veteran aquarists often have a difficult time defining what alkalinity actually is. Total alkalinity can be defined in a few different ways, but I'll use the definition that I believe will make the most sense to aquarists and that is most applicable to maintaining a marine aquarium.

But before we get to that definition, let's recall that there are a lot of minerals dissolved in sea water. Some of the ions can accept protons and in so doing act as bases. Consider our discussion of TCO_2 above. Bicarbonate ion can absorb up to one proton, to become carbonic acid,

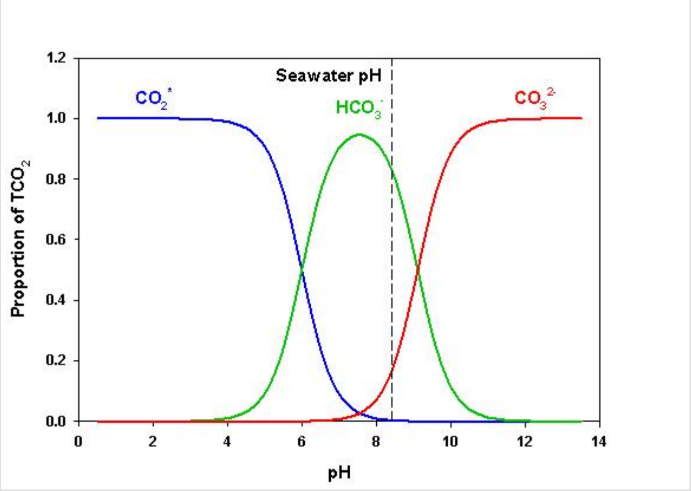

Figure 2. Speciation diagram for CO2 in sea water showing the relative proportion of each species. The speciation at normal seawater pH (pH = 8.20) is indicated by the dashed line. Values calculated for S =35, T = 25 °C, P = 1 atm.

Table 2. Conversion factors for the three scales typically used by aquarists to measure total alkalinity.

Starting units	**Convert to…**		
	meq/L	**dKH**	**ppm as $CaCO_3$**
meq/L	-	Multiply by 2.8	Multiply by 50
dKH	Divide by 2.8	-	Multiply by 17.9
ppm as $CaCO_3$	Divide by 50	Divide by 17.9	-

$HCO_3^- + H^+ \leftrightarrow H_2CO_3$

By the same token, carbonate ion can absorb up to two protons, to become carbonic acid,

$CO_3^{2-} + 2H^+ \leftrightarrow H_2CO_3$

While there are ions that can absorb protons, we already have some H^+ in our water, and we have some ion pairs that will readily donate protons. Thus there are not only ions that act as proton acceptors (bases), there are also compounds that act as proton donors (acids):

$HSO_4^- \leftrightarrow H^+ + SO_4^{2-}$

$HF \leftrightarrow H^+ + F^-$

The total alkalinity is the capacity of the bases in sea water to neutralize additional H^+, given that some H^+ ions are already present. In other words, the total alkalinity is the capacity to buffer against a *decrease* in pH. More formally we'd say:

Total alkalinity: The excess concentration of proton acceptors (bases) over proton donors (acids) in a water sample when that sample is titrated to the carbonic acid endpoint (pH ~4).

Alkalinity is a *property* of sea water (or any solution) rather than the quantity of a single ion or compound. In this way it is much like salinity. The salinity of sea water is made up of many dissolved species, though just a few components constitute most of the total. Likewise, the majority of the total alkalinity in sea water is provided by just a few ions with all the rest contributing a tiny fraction. We can define total alkalinity with the equation,

$TA = [HCO_3^-] + 2[CO_3^{2-}] + [B(OH)_4^-] + [OH^-] \ldots - [H^+] - [HSO_4^-] - [HF] - \ldots$

where "… " represents minor species.

Some of the total alkalinity is provided by bicarbonate and carbonate ions, collectively called carbonate alkalinity ($CA = [HCO_3^-] + 2[CO_3^{2-}]$). Some is provided by borate $[B(OH)_4^-]$, a bit is provided by hydroxide $[OH^-]$, and the small remainder is provided by a variety of other compounds (HPO_4^{2-}, PO_4^{3-}, $Si(O_2)^-$, $MgOH^+$, etc.). When carbonate alkalinity, borate alkalinity, hydroxide alkalinity, and all other sorts of alkalinity are summed together, we have the total alkalinity. Measuring the alkalinity provided by just one of these components can often be challenging. In contrast, measuring the total alkalinity is comparatively easy and can be done precisely and accurately with fairly simple equipment.

In normal sea water (S = 35, pH = 8.20), HCO_3^- contributes by far the largest portion of the total alkalinity at 89.8%. Carbonate ion is the next largest contributor with 6.7% of the total. Summing those two together we can see that carbonate alkalinity alone constitutes 96.5% of the total alkalinity in normal sea water. Alkalinity in sea water is mostly provided by carbonate alkalinity. The other large contributor to total alkalinity is $B(OH)_4^-$ at 2.9% of the total. Adding borate alkalinity and carbonate alkalinity together brings us to 99.4% of the total alkalinity contributed by just three species in normal sea water. Hydroxide contributes about 0.1% of the total alkalinity while all of the remaining sources of alkalinity combined contribute the remaining 0.5% in normal sea water.

In much the same way that temperature can be expressed on distinct scales yet measure precisely the same parameter (e.g., degrees Fahrenheit, degrees Celsius, Kelvins), aquarists commonly use three scales to express total alkalinity measurements:

1. meq/L (millequivalents per liter)
2. dKH (German degrees of carbonate hardness)
3. ppm as $CaCO_3$ (parts per million as $CaCO_3$)

Total alkalinity measurements can be readily converted from one scale to another (Table 2). Given that different scales are used to measure alkalinity, it is especially important to include units of measurement when discussing total alkalinity values with other aquarists. For example, an alkalinity measurement of "5" in a marine aquarium would be rather high if the unit of measure is meq/L, but quite low if the units are dKH. I will also simply note that oceanographers typically measure total alkalinity using a scale based on seawater mass instead of volume (meq kg^{-1} or µeq kg^{-1} vs. meq/L). Seawater mass is used by oceanographers because it can be measured more precisely than volume, and it is not subject to change with altered temperature or pressure whereas volume does change.

When normalized to S = 35, the total alkalinity of sea water averages about 2.35 meq/L (6.58 dKH) in the Atlantic and about 2.40 meq/L (6.72 dKH) in the Pacific. The small difference between oceans arises due to differences in the ages of the water masses in them (the "age" of a water mass being defined as the length of time since the water was in contact with the atmosphere). In the North Atlantic and in the Southern Ocean, near Antarctica, surface water sinks to the bottom of the ocean. This water then travels along the bottom of the Atlantic Ocean and past Antarctica. Along the journey $CaCO_3$ particles produced by phytoplankton and other organisms in the shallow ocean sink and dissolve in the deep sea, slightly increasing the total alkalinity of the sea water. The deep water then upwells in the Pacific and Indian Oceans, yielding higher normalized total alkalinity there. After upwelling the water travels along the surface through the Pacific and Indian Oceans into the Atlantic. Calcification by phytoplankton and other organisms removes a bit of the total alkalinity along the way and deposits it as $CaCO_3$ particles in the deep ocean. Removal of alkalinity by calcifying organisms from the water as it makes its way to the Atlantic and the dissolution of those minerals as the water makes its way to the Pacific yields slightly lower normalized total alkalinity values in the Atlantic and slightly higher ones in the Pacific.

Table 3. The major components of the carbonate system and typical values for standard sea water (S = 35, T = 25 °C, P = 1 atm, pCO_2 = 380 µatm).

Component	Mean value
Ca^{2+}	412 ppm
Mg^{2+}	1284 ppm
pH	8.20
Total CO_2	1991 µmol kg^{-1}
Total alkalinity	2.35 meq/L = 6.58 dKH = 119 ppm as $CaCO_3$

While the normalized total alkalinity does tend to be slightly higher in the Pacific than Atlantic, the higher salinity of the Atlantic Ocean yields slightly higher absolute total alkalinity values there. Just as with Ca^{2+} and Mg^{2+} above, variation in salinity from place to place causes some variation in absolute total alkalinity values as well. Total alkalinity ranges over ~2.35-2.48 meq/L (6.58-6.94 dKH) in the Atlantic (S ~35-37) vs. 2.27- 2.42 meq/L (6.36-6.78 dKH) in the Pacific (S ~33-35).

All of these values fall within the error of measurement of most hobbyist test kits though. While total alkalinity values of 2.3-2.5 meq/L (6.4-7.0 dKH) are readily distinguishable to an oceanographer with good equipment, hobbyist test kits are not precise enough to measure such small differences reliably.

Total alkalinity is an important parameter for us to consider for several reasons. First, it helps to stabilize our pH and buffer against a drop in pH. Second, the interaction between total alkalinity and total CO_2 largely controls seawater pH, as we will see. Third, HCO_3^- and CO_3^{2-}, for which total alkalinity is a proxy, constitute building blocks for $CaCO_3$ shells and skeletons. Hence, the alkalinity of sea water is intimately connected to the carbonate system in several ways.

CONCLUSION

In this article we've identified the major components of the carbonate system in sea water. Mean values for each of these parameters are summarized in Table 3. All of these components can be directly manipulated by the aquarist. By understanding the carbonate system and using that knowledge to our advantage it is possible to encourage rapid calcification and growth in many of the calcifying organisms we maintain in captivity. Next month we'll discuss how these components work together to provide the chemistry we measure in the aquarium, and in the ocean.

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EQUIPMENT REVIEW

TIME FOR CONDUCTIVITY

By Mark E. Evans

This article is an intervention of sorts, at least when it comes to simplifying one key aspect of the marine aquarium hobby - salinity (or specific gravity) testing.

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As aquarists we cheerfully feed our fish and invertebrates. We obsessively monitor their behavior and health, and adjust the parameters of their tiny environments as required. And we add and subtract chemicals by various methods so as to refine their water quality. As a result, our aquarium paraphernalia multiplies exponentially, like symbiotic bacteria. Evidence of this is in the observation that the meetings of most aquarium societies are also garage sales. This article is an intervention of sorts, at least when it comes to simplifying one key aspect of the marine aquarium hobby - salinity (or specific gravity) testing.

The cheapest and most common piece of equipment for testing specific gravity and, for determining salinity, is the plastic hydrometer. For those with a greater scientific inclination it is the buoying and bobbing, glass hydrometer. For those who dig the most modernity and coolness, it is the light utilizing refractometer. But each of these tools suffers from the same drawback of being able to perform only a single function; they only have one purpose, and they take up space when they are not performing it. So, the question is, wouldn't a multipurpose gadget be more preferable in a hobby that is so often fraught with clutter?

This used, lab grade refractometer was found on an auction website for about $40. A salinity refractometer works on the principle that the degree of light refraction increases with liquid density, i.e., the denser the water, or the more dissolved solids it contains, the more it bends the light that passes through it. A prism, with a thin film of water on its surface, provides a mechanism for observing and measuring this refraction.

An electronic conductivity meter is just such a gadget. Not only can one be utilized to determine salinity, but it can also be applied to testing freshwater sources such as municipal tap water, well water, rainwater, and RO/DI water. After all, a significant percentage of marine aquarium enthusiasts also have experience in the freshwater hobby, in which a conductivity meter is a valuable measuring tool for matching or manipulating a water source to the needs of delicate fish species.

Consider also the unstable nature of an aquarium's water chemistry. Without the aid of protein skimming or water changes, a marine tank readily accumulates metabolic waste products: Nitrogen compounds, carbon dioxide, phosphates, sulfates, etc. (Some compounds such as carbohydrates --basic sugars-- add to conductivity only after they've been metabolized). So, either uneaten food is broken down, is mineralized into electrolytes, adding directly to conductivity, or the through the metabolic processes of a tank's animal inhabitants, it is transformed into conductive waste products. The other source of electrolytes is, of course, the addition and subtraction of salts and aquarium additives. (Evaporation itself doesn't add any more electrolytes; it simply concentrates them per volume of water, thus increasing conductivity). For a basic list of electrolytes, see Table 1.

Freshwater fishes live in water that is of a lesser ionic concentration than the cells in their bodies; they are hypertonic compared to the water. So, in effect, they live under osmotic pressure and are constantly gaining water, which they must expel in the form of dilute waste. They are also continually losing salts, which they must conserve through processes in their kidneys and gills. Freshwater fishes thus have little need to actually drink water; it's literally forced into their bodies. (Osmostic pressure is the result of molecular movement and a differential in ion concentrations. Molecules move from an area of higher concentration to one of lower concentration. This is called Brownian motion, and it's evident in a room in which a match has just been lit; the smoke quickly disperses to fill the space.)

Marine fish live under the opposite conditions, in water that is of a greater ionic concentration than the cells in their bodies; they're hypotonic compared to the water. So, they are constantly losing water through osmosis and conserving salts. To counter the loss of water and conservation of salts, they take in water and expel concentrated waste to rid themselves of excess ions. (All but a few species --salmon, eels, one of two of the sharks-amazingly have the ability to survive in, and cross between, both fresh and saltwater environments.)

Table 1: Constituent Electrolytes Of Water (List is not comprehensive)

Negatively Charged Anions	Positively Charged Cations
Sulfate (SO4--)	Sodium (Na+)
Silicate (SiO3--)	Potassium (K+)
Phosphate (PO4---)	Magnesium (Mg++)
Nitrite (NO2-)	Iron (Fe++)
Nitrate (NO3-)	Hydrogen (H+)
Hydroxide (OH-)	Copper (Cu++)
Carbonate (CO3--)	Chromium (Cr++)
Chloride (Cl-)	Calcium (Ca++)
Bi-Carbonate (HCO3-)	Ammonium (NH4+)

So, as we can see, dissolved solids play a vital role in the general physiology of fish. Too low or too high a level can have a deleterious effect on growth and overall health, e.g., dissolved calcium is utilized in bone building in fish, and developing fish eggs exchange ions across their permeable membranes. An ionic imbalance in the former case could lead to a developmental disorder, and in the latter case an egg that will fail to hatch. (The necessity for a continuous supply of electrolytes can be observed in the behavior of male Clownfish when they meticulously tend their female's eggs by cleaning and fanning them.)

A proper explanation of the concept of conductivity is probably best left to the experts. The manufacturer of the conductivity meter in picture #3 presents the following glossary definition on its website:

"The ratio of the electric current density to the electric field in a material. Some materials such as metals, copper, silver, gold, platinum have very high conductivities but other materials such as plastic may have a very low conductivity. Seawater contains a large quantity of dissolved salts therefore, has a high conductivity. De-ionized water (DI) has a low conductivity."

This rugged and easy to use TDS meter has a range of 0-5000 ppm (parts per million), and operates on a single 9-volt battery. A small well holds the water sample, about 5ml. Lacking an analog or a digital display, the measurement is made by holding a button down and adjusting a dial along a graduated scale until an LED illuminates. A switch on the base changes between three range multipliers: 1, 0.1, and .01, in effect, making the meter's effective ranges 0-5000, 0-500, and 0-50, respectively.

Conductivity meters are such simple devices - two electrodes powered through a circuit -that numerous companies manufacture them. Their cost is also affordable for those serious aquarists who are also willing to fork out for other types of monitoring equipment like pH testers. For the purpose of marine aquariums, it is the testing range of a meter that is important. Generally, a meter measures in µmhos (micromhos), - equivalent to µS (microSiemens) which is used in Europe - or parts per million (ppm) of total dissolved solids in the case of TDS meters. But the two different units are easily converted into one another. (Multiply micromhos by 0.7 to convert to ppm.)

Commercially available conductivity meters test in a wide range, starting in the low range of 0 - 10 µmhos, to the high range of 100 - 200,000 µmhos. For the purposes of marine aquariums, however, this poses a slight problem. Seawater has an average density of about 1.027 gm/cm^3, fluctuating around the world from about 1.020 gm/cm^3 to 1.029 gm/cm^3. This converts to a conductivity of 35,000 ppm or 50,000 µmhos. So, it would seem only logical to use a meter that has a high range, greater than what is found in marine waters, such as 100,000 µmhos. But as we shall see, this is not necessarily the case. To avoid having to purchase an expensive high range meter or monitor, we can instead make a small compromise in our testing method.

If your conductivity meter doesn't measure within an appropriate range for a marine aquarium, it doesn't mean you're unable to perform a test. If you carefully dilute the tank water sample to be tested with freshwater - with RO water, distilled water, or low

Another handheld conductivity meter with the well design. Two separated electrodes are embedded in the well. The liquid being tested acts as the conductor and competes the circuit. This meter has an overall range of 0-10,000 µS (microSiemens), which are equivalent to µmhos (micromhos). It was also purchased on an auction site for about $40.

conductivity tap water - you can make a measurement. For example, if we have a conductivity meter with a range limit of 10,000 µmhos, we can mix 1 part tank water with 3 parts freshwater, thus placing the resulting mixture within the range of the meter. To determine the actual conductivity, we simply multiply the meter's reading by 4.

One drawback with using a conductivity meter is that it requires periodic calibration. But there's no need to waste money on purchasing - and throwing away - a laboratory grade, standardized calibration solution. (For the best results, distilled or RO water --with a near zero reading-- should not be used here because the meter will be used to test high-conductivity marine water. Ideally the calibration solution should be close to the same level as the water being tested.) By bottling a sample of seawater that is already known to have the proper salinity and to be within the proper salinity range for the tanks' animals, this problem can be easily solved. You can prepare a standardized solution for calibration use by weighing 4.7 ounces of salt mix and dissolving it in a gallon of freshwater. (Some salt brands have slightly higher moisture contents than others, so take this into account when mixing.)

This high-range conductivity meter measures up to 100,000 µmhos, with its lowest range setting being 0-10 µmhos (micromhos). It requires a special probe and calibration, and a bank of 8 AA batteries to operate. But it is effective at both determining the salinity of a sample of diluted saltwater and the efficiency of a RO/DI filter system.

At this point you may still be wondering what the point is of fussing about with electronic meters and diluted salt solutions, when refractometers are so readily available. My response to that would be, saving money and taking pleasure in one's hobby. A refractometer is a solid device with which little can go wrong, but, like a garlic press, it only performs a single function. The rest of the time it's a paperweight taking up space. A conductivity meter, on the other hand, is capable of testing and monitoring tank water, reverse osmosis source water, and municipal tap water. And while I don't get a great deal of pleasure out of performing water changes on my aquarium, I do always gain some gratification in playing scientist with my conductivity meter… and in feeding my tank's inhabitants, of course.

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MEDIA REVIEW

INFORMATION RESOURCES FOR HOME AQUARISTS

By Jay Hemdal

Jay reviews different information resources for marine aquarist.

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Every aquarist, no matter their experience level, will eventually have questions regarding some problem they are facing with their aquarium. Getting an appropriate answer to these questions is vitally important; the lives of the animals in your care depend on it. Receiving incorrect information and then acting on it (as you may not know any different) can be more detrimental for your animals than taking no action at all. The following is an overview of the typical informational resources available to home aquarists, along with some benefits and potential drawbacks of each:

Books - Prior to the advent of the Internet, print books were one of the primary informational resources for home aquarists. Because of the competitive nature of getting a book published, combined with (usually) extensive editorial oversight, books generally contain accurate information. Of course, some are better than others, but because it is so costly to produce a print run of books, few publishers wish to risk being stuck with a "dog", so they keep close reins on their authors. Beware of "self-published" titles - these are always written by people who have first tried to interest a mainstream publisher in their book, but failed. This means that the publishers did not feel the quality was up to their standards, or that the book lacked sufficient marketability.

Most professional aquarists with information that they want to share with the greatest number of other people still choose books as their primary venue. There is something about the permanence of a book that holds great appeal for most authors.

Electronic magazines - Internet magazines have become a boon for aquarists. Usually having free access, the fast publication schedule of these "e-zines" means that aquarists can have access to the freshest information possible. Along with that rapid publication speed does come some increased potential for errors or omissions - but by virtue of the material being online; corrections take only seconds to perform. There is also a tendency for online magazines to be able to avoid some of the pitfalls of print media - since web hosting space is so inexpensive, there are fewer problems with article length, number of photographs, etc., that plague print magazines. Too often, an article for a print magazine is called for like this: "We need 2400 words on dottybacks with six images and two sidebars." This results in the author changing the article to fit the publisher's needs - perhaps for the worse, especially if they had originally wanted to write 3500 words, and had 20 images to go with it!

Fellow club members - People who join their local aquarium club have a ready source of information in talking with other members. The primary benefit of this is that fellow members will have good knowledge of the local aquarium business scene - which stores are good, which ones are a bit less so. Also, since most of the interaction takes place face-to-face, there is less chance of ambiguity ruining the advice given. Finally, since the advice flow is so personal, people take great pains to be as accurate as possible, as any bad advice given may well come back to haunt them at the next club meeting. Some drawbacks include the fact that many members are on the same level in terms of hobby experience, so the really tough questions may go unanswered. Some clubs are subsidized by local pet stores, so there may be a commercial slant to overcome. Finally, it seems that many hobby clubs suffer from internal political problems - one faction trying to take control, or certain people being ostracized, etc.

Extrapolation from other sources - Except for public aquariums, the aquarium hobby (and its information sources) are mostly non-professional. This leads some aquarists to seek out professional information from related fields such as veterinary or human medicine, marine biology or chemistry. While this professional information (that was usually peer-reviewed) is precise in its own context, its application when extrapolated to home aquariums may not always give suitable results. One example was a paper from Varner and Lewis in 1991 that associated a virus with cases of Head and Lateral Line Erosion (HLLE) in *Pomacanthus* sp. angelfish. This caused many home aquarists to believe that HLLE is a communicable disease, as most viral infections are. The problem is that subsequent studies have created doubt surrounding the virus actually being the cause of HLLE, and nobody has every demonstrated transfer of

Books, magazines and pamphlets can all be reasonably good sources of aquarium information.

HLLE from one fish to another in a manner that suggests that it is a contagious disease.

Internet forums - This form of information exchange is by far the most commonly used at the present time. Since the member base of most of these groups is huge, there is a wealth of information to draw from. Many forums are very active, meaning that answers to questions may be posted within minutes or hours. However, aquarists need to plan their information requests somewhat; posting an emergency question at 2 a.m. on a Monday morning will probably not result in a proper response within a hoped-for 30 minute time frame.

There has also been the creation of what is termed "Niche Experts" - people on a particular forum, (or section of a forum) that have become the local expert on certain topics. Utilizing them for information works well as long as these people supplying the information are truly experts in their fields and not that they just know "just a bit more" than the people they are responding to. Another problem is when these niche experts then begin to expound on other topics that they are not quite as familiar with. Their status as an expert belies the fact that they do not have as strong of a knowledge base on other topics that they might branch out into.

Manufacturers - Manufacturers should be responsible for supplying technical information about the products they produce. Some forward-thinking manufacturers have produced their own newsletters or even short magazines that provide general information about the aquarium hobby. Of course, everyone understands that their primary business is to sell product, so it is expected that the information that they provide would support that goal in some way. There is not anything inherently wrong with this combination of business and information flow - as long as it is kept to reasonable levels.

Print magazines - Print magazines are positioned between books and Internet resources in terms of timeliness of their information. In regards to accuracy, most articles are reviewed by editors who are familiar with aquariums, so most errors are corrected before they reach print. It is suspected that some magazines must kowtow to manufacturers who advertise with them; to the degree that they do not allow certain topics to be covered that might negatively impact the sales for those manufacturers. The most common example of this is a distinct lack of comprehensive product reviews in most magazines. With the advent of the Internet, there seems to have been a corresponding general decline in print magazine sales. While most of these magazines have remained in operations for many years, overall subscription rates seem to be gradually declining. One magazine had seen monthly distribution of 50,000 copies 30 years ago, and this has decreased to around 20,000 copies a month today.

Personal research - Simply put, this information resource is when the aquarist cannot find an answer for a problem, and researches the issue for themselves. For example, I once needed to calculate a very critical dosage for a medication. I needed to know the exact volume of water contained in the aquarium, including the amount found in the interstices of the gravel - and add that into the calculation. During one lunch hour, I had run a series of tests using gravel and graduated cylinders, I soon discovered that about 30% of a layer of regular sized aquarium gravel is actually water, and was able to factor that in to my dosage calculation. Of course, this only works well for simple, narrowly focused questions such as this. Problems such as "all my fish just died, why?" do not lend themselves well to this particular technique.

Pet store employees - Often, the frontline informational resource for beginning aquarists is the pet store employee. These store workers need to be able to respond daily to inquiries such as, "what filter should I buy?", and "will these fish be compatible with those that I already have?" Since you are their customer, they have a vested interest in your success. However, not all store employees are up to this challenge, so if you find a knowledgeable one, learn their work schedule and preferentially shop with them. Similar to aquarium clubs, since the information exchange is usually face-to-face, the person dispensing the advice has a personal interest in trying to give you the most accurate answer possible - to avoid having the problem come back to them should the advice fail.

Web pages - The Internet has substantially changed how home aquarists gather, process and implement information about their aquariums. "Googling" has become a verb. This is the resource that I generally use myself. Web searches will result in a wide variety of information, from technical papers, to online aquarium magazines to threads on Internet forums. I feel that I have enough experience to separate the "chaff from the seed" and can quickly discount any erroneous information that may show up in the search engine results. Because the search engines work best when fed just a single word or a term, they are not well-suited for broad questions such as "how many fish can I safely add to my 20 gallon aquarium?"

The Internet is a special case. I was very active on CompuServe's FISHNET forums back in the 1980's, but had not been very active on

A simple experiment to measure of the volume of water held in the interstices of gravel showed that about one third of the volume of a gravel bed is actually water.

the newer web based forums until recently. I've noticed a disturbing trend where certain bad ideas taken hold on certain forums, and people have gotten lax in the answers. In particular, the fish disease forums are rife with poor advice. This article actually began life as a rebuttal to a self-proclaimed niche-expert who was dispensing horribly bad advice on fish disease treatments. I tried a posting polite correction and when that went unheeded, I was a bit more assertive; but all I received as a result was a scathing IM from the person. The following is a compilation of some of the problems with information quality that I've seen in various aquarium forums over the past few years. The wording of these may not always be exactly the same, but the general ideas keep resurfacing:

1. "I drip-acclimated my fish for XX hours just like I was told." XX can be anything from four to eight hours, sometimes more. There are only two specialized instances where acclimation times this lengthy are justified: when moving a fish from lower specific gravity to a tank that is much higher and in cases where the shipment time was in excess of 36 hours. In both of these instances, life support is maintained by aeration and keeping the temperature within range. In the case of lengthy shipments, the pH / ammonia issue must be dealt with.

Think about this - you have been outside without a coat, you are hypothermic, you are then given the choice of going inside and sitting by a space heater or moving into the garage to warm up just a little, and then an hour later, go into the house - your choice is? It is the same with fish and inverts - any temperature acclimation times of more than 15 minutes are useless. Temperature shock is a much rarer thing than you might think - many more fish die due to low dissolved oxygen or high ammonia while being acclimated too long for temperature (Hemdal 2006). Perhaps worry about photo-shock, pH change and specific gravity increases, but don't go overboard. Ultimately, ask yourself; what is more stressful to a fish - acclimating them in a bare Styrofoam box or bucket for five hours, or having the water parameters abruptly change, but then being able to hole up undercover in a dark cave inside a good quality aquarium to recuperate?

2. Hyposalinity treatments are "a soothing tonic" for marine fish and need to be run at a specific gravity of 1.009 for six weeks. No: This treatment is stressful, as evidenced by the number of *Uronema* protozoan outbreaks I've seen when people try this. In my opinion, although many fish can tolerate 1.009, there is no reason to go below 1.0125 - this is the original treatment refined by public aquariums about 30 years ago.

3. Question, "My fish has cloudy eyes, what should I do?" Too many times people post their overly concise answer as "Move to a quarantine tank and treat with antibiotics".

Flukes can cause cloudy eyes, injuries cause cloudy eyes, fish can develop cataracts. Nobody can diagnose bacterial diseases based on simple written symptoms! You need to ask follow up questions and offer some alternatives.

4. "Give your fish a 30 minute freshwater dip". There is no justification for performing a freshwater dip longer than 7 minutes, and five is usually tolerated much better. I am amazed to hear a pundit explain how to carefully adjust the temperature and pH of the dip water to that of the tank (to avoid stressing the fish) and then tell the same person to dip the fish for 30 minutes in freshwater….no THAT isn't stressful.

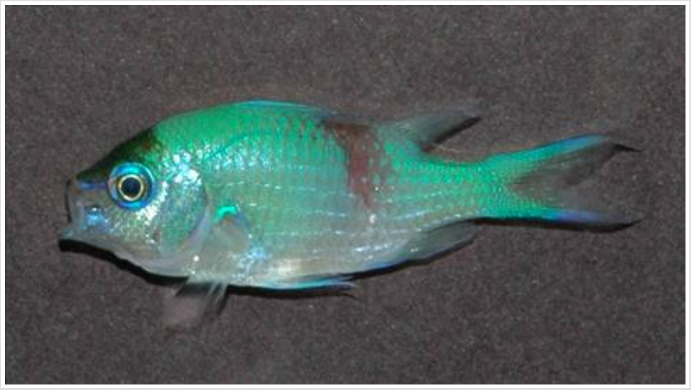
5. One sentence answers to just about ANY fish disease question. Does anyone really think that people have the magical ability to diagnose and treat fish disease problems in 10 words or less without at least some follow up questions?

6. Don't give out human medical advice unless you are a physician. Don't give your opinion on things like "Help, I was stung/bitten by my fish", or "I inhaled/swallowed this chemical, what should I do?" Don't give out structural engineering advice unless you are an expert. There is a reason why these people need to be licensed. If you do decide to dispense professional advice without actually being a professional, at least add sufficient disclaimers to your post.

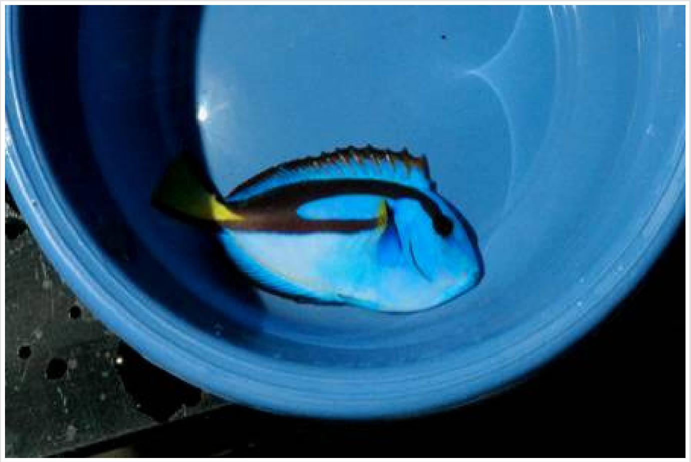
7. Any problem solution that has as its main advice, "Feed vitamin C and/or garlic". There needs to be some references here that are not purely anecdotal. If you prescribe a medication that starts with the word "super" or "magical" ends with "- fixit" or "- cure-all" think twice - and then at least tell the person what the active ingredient is. Wait, they don't list the ingredients on the label? Hmmm, now that might be a problem……

Now - the people posting responses to problems are not the only issue; the person who initiates the thread has some responsibility:

8. Don't post ambiguous, short messages about a fish problem with no pictures and expect to get any meaningful advice.



This green chromis died from an infection of the protozoan Uronema, yet based on its gross visual symptoms, most people would have suspected a bacterial infection.



A blue tang undergoing a freshwater dip is being moderately stressed.

9. Go ahead and ignore replying posts that give advice you don't want to follow, can't afford or don't want to accept, but be prepared for possible continuing problems.

10. Don't wait too long before posting. Problem reports that begin with "I lost three fish today, two yesterday and one the day before that…." are probably not going to end well for the rest of the fish (no matter what advice you are given) now that its day four.

11. Check the answers you get from strangers on the Internet with information from published sources. "Fish Doctorz" advice may sound really good, but he could be some junior high kid with his first tank just "chillaxin" and tossing out random bits of information on the forum because it makes him feel important.

12. Check the FAQ! You most likely are not the first, (or even the fiftieth) person to post a question about HLLE - research the forum before posting commonly asked questions.

As a pet store department manager in the early 1980's to working as a public aquarium curator at the present time, I've fielded tens of thousands of questions from hobbyists about their aquariums. The questions have run the gamut of dealing with new tank syndrome in a goldfish bowl to advice on how to build a 2500 gallon shark tank.

I use a series of informal rules whenever I attempt to answer questions from aquarists, these same rules may help others dispense better advice as well:

1. If I don't have adequate first hand knowledge about the animal in question, I tell the person I cannot help them. Too many "experts" feel strangely compelled to give answers about something they have no direct knowledge of.
2. Always ask enough questions and gather enough background information, (through water tests, etc.) so that a reasonable solution (or range of solutions) to the problem can be given.
3. The most common problem is usually the correct diagnosis; a newly established tank is probably suffering from ammonia poisoning and not a result of toxic water from some unknown chemical reaction.
4. When answering a question about a fish that you have not seen firsthand, never give your answer in absolutes, rather say; "your fish may have *Cryptocaryon*" instead of "your fish have *Cryptocaryon*". This gives the person pause for thought, and they are more likely to double check your answer. Always conclude your advice with a strong caveat that the person should seek a second opinion, and that because you cannot actually see the animal, you have to formulate a solution based solely on the information they provided.

One final note on misinformation - it seems that chronic problems with aquariums are the issues where the most misinformation abounds. Head and Lateral Line Erosion, *Aiptasia* anemone removal, *Lymphocystis*, what size of a tank does a fish need, are all issues where not only is there a lot of room for different opinions, but there is TIME for the aquarist to seek out information from a variety of sources.

In some cases, people tend to blame others for their animal losses: "I bought this fish and it got sick, and the store told me to treat it with this product, but it died" does not mean that the store was at fault. It was your fish, under your care when it died. Ultimately, I think that all aquarists need to understand this, and I feel they know that deep down; they are completely responsible for gathering and then applying appropriate information in order to care for their aquariums in the best possible manner. Just the fact that you are given bad or incomplete advice does not mean that you have to use it, check and re-check your information so that your aquariums are cared for properly.

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